

Detections of SiO Masers from the Large-Amplitude Variables in the Galactic Nuclear Disk

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Abstract

We have surveyed known large-amplitude variables within 15' of the Galactic center in the SiO $J=1-0$ $v=1$ and 2 maser lines at 43 GHz, resulting in 79 detections and 58 non-detections. The detection rate of 58 percent is comparable to that obtained in Bulge IRAS source surveys. SiO lines were also detected from four other sources near the program objects. The SiO detection rate increases steeply with the period, particularly for stars with $P > 500$ d, where it exceeds 80%. We found at a given period that the SiO detection rate is approximately double that for OH. These facts suggest that the large-amplitude variables in the Nuclear Disk region are AGB stars similar in their overall properties to the inner and outer bulge IRAS/SiO sources.

Key words: Galaxy: center, kinematics and dynamics — masers — stars: AGB and post-AGB

1. Introduction

The dynamical behavior of the central region of the Galaxy has attracted much attention (000 [cite]cite.mor96Morris, Serabyn (1996)). Since the bar-like structure of the Galactic bulge was discovered (000 [cite]cite.bli91Blitz, Spergel (1991); 000 [cite]cite.nak91Nakada et al. (1991); 000 [cite]cite.dwe95Dwek et al. (1995)), it has been recognized that non-circular motions must be taken into account when interpreting observational data, such as the CO gas distribution in the central nuclear disk (000 [cite]cite.bin91Binney et al. (1991)). Because double bars and nuclear rings have been proposed as efficient mechanisms for feeding gas into the centers of galaxies (000 [cite]cite.shl89Shlosman et al. (1989)), it has become additionally important to look for signs of non-circularity in the motions of gas and stars.

As a consequence of interstellar extinction, it is impossible to make measurements of the radial velocities of stars in this region at visible wavelengths. Most such information comes from radio observations of SiO and OH masers which are not affected by interstellar extinction. A considerable amount of data is now available (000 [cite]cite.lin92aLindqvist et al.

(1992); 000 [cite]cite.deg00aDeguchi et al. (2000a)a,b). The masers arise in the atmospheres of mass-losing stars on the Asymptotic Giant Branch (AGB), which are intrinsically bright in the mid-infrared region, and which can potentially be identified at these wavelengths. However, the source densities within one degree of the Galactic center are so high that the main mid-infrared Catalog, the IRAS PSC, is very incomplete. Blind surveys in OH and SiO maser lines for AGB stars have been made (000 [cite]cite.sjo98Sjouwerman et al. (1998); 000 [cite]cite.shi97Shiki et al. (1997); 000 [cite]cite.miy01Miyazaki et al. (2001); 000 [cite]cite.deg02Deguchi et al. (2002)), but they are limited in sensitivity by short exposure times, and faint objects were difficult to detect compared with the pointed surveys. This situation, however, has recently changed owing to new ground-based surveys with near-infrared array cameras, such as 2MASS and DENIS, and to space-based mid-infrared surveys, such as MSX and ISOGAL (000 [cite]cite.pri01Price et al. (2001); 000 [cite]cite.omo99Omont et al. (1999)). Large numbers of candidate stars suitable for maser surveys toward the nuclear disk have been discovered in the near-infrared K band (000 [cite]cite.gla01Glass et al. (2001)) by making use of their characteristic large-amplitude variability.

In this paper, we report on preliminary results of an SiO maser survey of Large Amplitude Variables (Miras or semiregulars; abbreviated as LAV hereafter) within 15' of the Galactic center (000 [cite]cite.gla01Glass et al. (2001)), whose amplitudes and periods are known (000 [cite]cite.woo98Wood et al. (1998); 000 [cite]cite.gla01Glass et al. (2001)). Because these stars are located at approximately the same distance (about 8 kpc) from the Sun, they constitute an ideal sample for studying the statistical characteristics of AGB stars and their detectability in the maser lines. In addition, surveying these sources gives accurate radial velocities, and provides basic data for investigating the kinematics of the Galactic nuclear disk.

2. Observations

Simultaneous observations in the SiO $J=1-0$, $v=1$ and 2 transitions at 42.122 and 42.821 GHz, respectively, were made with the 45-m radio telescope at Nobeyama during 2001 February–May. Details of SiO maser observations using the NRO 45-m telescope have been described elsewhere (000 [cite]cite.deg00aDeguchi et al. (2000a)a), and are not repeated here.

The sources were taken from the Glass et al. (2001) list and were selected for long periods ($P > 450$ d) and good-quality light curves ($Q = 3$). Additional LAV stars which do not satisfy the above criteria were also chosen because of OH 1612 MHz detections and positional coincidences with MSX sources (000 [cite]cite.pri01Price et al. (2001)). The positions of the stars were taken from table 2 of [cite]cite.gla01Glass et al. (2001) ([cite]cite.gla01Glass et al. (2001)), which are sufficiently accurate (\sim a few arcsec) for a telescope beam size (HPBW) of about 40".

In total, 134 LAVs were observed during the winter–spring season of the year 2001, and we detected SiO maser emission towards 76. According to the convention of [cite]cite.gla01Glass et al. (2001) ([cite]cite.gla01Glass et al. (2001)), we write their names as the field and star numbers, preceded by “g” for [cite]cite.gla01Glass et al. (2001) ([cite]cite.gla01Glass et al. (2001)). We tried to observe all of the stars with $Q = 3$ and $P > 450$ d in the [cite]cite.gla01Glass et al. (2001) ([cite]cite.gla01Glass et al. (2001)) sample, but two sources (g23–3305 and g19–7) were left unobserved because of limited observing time.

The detected sources and their radial velocities (average of the peak radial velocities in the $J=1-0$ $v=1$ and 2 transitions) are given in table 1. The full line parameters (antenna temperatures, integrated intensities, etc.), as well as null results, will be presented in a future paper.

The high stellar density near the Galactic center occasionally led to the finding of an additional source within the 40" telescope beam; we saw two peaks in the spectra. The number of detections are, in fact, more than 76. Table 1 lists 7 such sources. Most of these extra peaks can be assigned to nearby OH sources or Glass et al.’s LAVs, except for two (g12–21 and g19–7). Because we can easily find possible counterparts for each component in the doubly peaked cases, we are confident that none of these spectra

correspond to single sources similar to the Orion IRc2 SiO masers (see the discussion in 000 [cite]cite.deg99Deguchi et al. (1999)). In the case of g9–8, we detected double peaks in the spectra; the star g9–547 is close by (13" separation). We took another SiO spectrum at a position 15" offset towards g9–547, and confirmed that the relative intensities of the two peaks changed in the expected manner. Thus, the identifications of these two sources are certain.

We checked the radial velocities of the 36 OH 1612 MHz maser counterparts that are within 5" of the positions of LAVs. The OH radial velocities (the average of the OH double-peak velocities) of 32 counterparts were consistent with the SiO radial velocities. For these 32 sources, the average SiO–OH velocity difference was $(V_{\text{SiO}} - V_{\text{OH}})_{\text{average}} = 0.59 \text{ km s}^{-1}$ (with standard deviation of 1.93 km s^{-1}). In addition, we found that one source, g20–136, has $V_{\text{lsr}} = -85.6 \text{ km s}^{-1}$, which is not inconsistent with the single-peak OH detection at $V_{\text{lsr}} = -116.8 \text{ km s}^{-1}$.

The SiO radial velocities of three stars were not consistent with the OH velocities: g4–113 (OH 359.855–0.078), g13–200 (OH 0.178–0.055), and g22–274 (OH 359.791–0.081). The positions of two sources coincide with the OH positions within 3", the exception being g13–200. We also looked at OH sources within 40" of the SiO sources, but found that none of them had similar radial velocities. These unidentified SiO sources are possibly obscured AGB stars within the telescope beam or, in the case of OH 0.178–0.055, may be an AGB star that is not the OH source; g13–200 is separated from OH 0.178–0.055 by 5".1 (see table 6 of 000 [cite]cite.gla01Glass et al. (2001)), which is too large to be a measurement error.

Twenty-three stars in the present sample have MSX source counterparts within 3σ of the MSX positions (a few arcsec; 000 [cite]cite.pri01Price et al. (2001)). They are indicated by “§” signs in table 1. The MSX subset contains 14 detections of SiO and 9 non-detections, giving a 61% SiO detection rate. The rate for the MSX counterparts is similar to the average detection rate, 59%, of SiO in the full sample. These sources have flux densities of 0.3–4 Jy in the MSX band C ($\sim 12 \mu\text{m}$) with colors not very different from the IRAS/SiO sources in the Bulge (e.g., 000 [cite]cite.izu95Izumiura et al. (1995)).

3. Discussion

3.1. Period–SiO Detection Rate

Figure 1 shows the period distribution of the observed sources and the SiO detection rate (line graph). The sources with $P > 450$ d (and $Q = 3$) were preferentially observed in the present survey so that the peak occurs in the 500–600 d bin. Note that the average period of the [cite]cite.gla01Glass et al. (2001) ([cite]cite.gla01Glass et al. (2001)) sample is about 430 d. This figure clearly shows that the SiO detection rate increases with the period. The dotted line in figure 1 indicates the OH detection rate, which seems to correlate with the SiO detection rate quite well. The SiO detection rate, however, is twice

Table 1. SiO radial velocities of the detected sources.

Name	V_{ave} (km s ⁻¹)	Name	V_{ave} (km s ⁻¹)	Name	V_{ave} (km s ⁻¹)	Name	V_{ave} (km s ⁻¹)
g1-8	79.0	g4-23	3.4	g10-392	94.3*	g17-630	-9.8*
g1-31	-38.6	g4-113 [§]	-279.0 ³	g11-4503	7.9*	g17-3762	-49.0*
g1-72	21.1	g4-253	-46.0	g12-13	-19.5	g18-14	-39.1
g1-1890	23.6*	g4-557	-85.1*	g12-21	33.3, 71.5 ⁵	g19-2	-17.8
g2-1	-5.9*	g5-159	-2.4*	g12-51	44.4*	g19-7	-107.1, -31.9 ⁸
g2-3	-7.5	g5-2856	72.3*	g12-228	-74.3	g19-476	-75.0*
g2-28	36.0*	g6-25 [§]	-0.8	g13-16	83.2	g19-685	-53.5 ⁹ , -44.2*
g2-52	105.5	g6-85	88.1	g13-18 [§]	16.2	g20-26 [§]	-38.4*
g2-697	-52.5*	g6-135	5.8*	g13-33	124.8*	g20-136	-95.4 ¹⁰
g2-6329	120.4*	g7-13	5.3	g13-55	37.4	g21-12	-19.7
g3-5	35.9 ¹ , 52.6*	g7-20	-55.7	g13-200	23.7 ⁶	g21-39 [§]	-65.1
g3-6	22.9	g8-11	-32.4	g14-2 [§]	-58.6	g22-4 [§]	-68.6*
g3-226	134.2*	g8-31 [§]	108.5	g14-6 [§]	-32.5	g22-7	-68.0
g3-266	-73.0*	g8-53	-27.1	g14-11	-60.1	g22-11	-197.3
g3-358	12.8*	g9-8	-4.4, 72.3 ⁴	g16-1 [§]	-5.2 ⁷ , 22.1	g22-22	-11.4
g3-779	-142.3*, -47.6 ²	g9-9 [§]	23.1	g16-8	-38.9	g22-76	-77.3 *
g3-2752	5.7*	g10-5	70.0	g16-25	-61.2	g22-274	-85.6 ¹¹
g3-2855	-308.1*	g10-6	39.6*	g16-36 [§]	50.2	g23-5 [§]	-20.8
g3-7655	-7.5	g10-84	-27.9*	g16-150 [§]	-131.5*	g23-8	-109.0

* The SiO radial velocity is consistent with that of OH 1612 MHz counterpart.

[§] The star has a MSX counterpart (within 3σ of the MSX position uncertainty).

¹ the 35.9 km s⁻¹ component is from either OH 359.958-0.058 (27".2 away) with $V_{\text{lsr}} = 41.7$ km s⁻¹ or OH 359.952-0.058 (32".9 away) with $V_{\text{lsr}} = 36.4$ km s⁻¹.

² the -47.6 km s⁻¹ component is probably g3-1030* (OH 359.906-0.036, 20".8 away).

³ OH 359.855-0.078 at 3".1 separation has a velocity at 4.8 km s⁻¹.

⁴ The 72.3 km s⁻¹ component is g9-547* (OH 0.040-0.056).

⁵ Close to g12-65 and g12-42, definite assignment impossible.

⁶ OH 0.178-0.055 at 5".1 separation has $V_{\text{lsr}} = -36.6$ km s⁻¹.

⁷ the -5 km s⁻¹ component is OH 359.867+0.030 with $V_{\text{lsr}} = -3.7$ km s⁻¹ (9".6 away).

⁸ the g19-9 is located very close; definite assignment impossible.

⁹ the -53.5 km s⁻¹ component is probably g19-128 which is located nearby.

¹⁰ OH 359.791-0.081 at 0".7 apart has a single peak at -116.8 km s⁻¹, not inconsistent with the SiO velocity.

¹¹ OH 359.778+0.010 at 3".3 apart has $V_{\text{lsr}} = -27.5$ km s⁻¹. The -85.6 km s⁻¹ component may possibly be g22-1 at 20".6 away, but this source was not detected in 2001 May (weather conditions poor).

as high as the OH detection rate, indicating that an SiO maser survey can double the number of stars with radial velocity data near the Galactic center.

That the maser detection rate increases with the period of light variation in LAVs has already been suggested by observations of stars near the Sun (e.g., 000 [cite]cite.ben96Benson, Little-Marenin (1996)). However, because of uncertainties in the distances of these stars, the relation was not demonstrated clearly. In the present sample, the distances to the LAV stars are almost equal and the correlation with period is much more striking.

3.2. Velocity Distribution

Figure 2 shows longitude-velocity diagram for the detected sources. Most of the radial velocities fall within ± 200 km s⁻¹. Two extreme sources at $V_{\text{lsr}} = -279$ and -308 km s⁻¹ occupy outlying positions. These sources might be outer bulge objects in highly eccentric orbits,

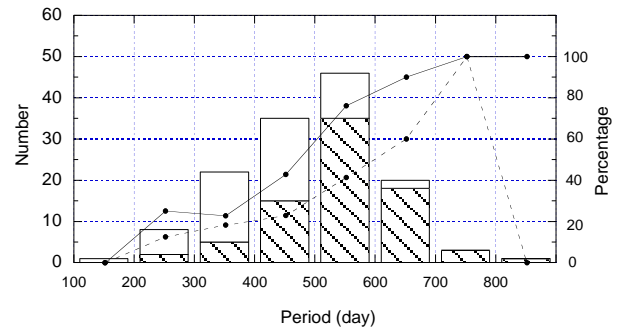


Fig. 1. Histogram of period and detection probability (line graph). The shadow and blank in the histogram indicate the SiO detection and nondetection, respectively. The solid and broken lines (unit at the right vertical axis) indicate the detection rate of SiO and OH masers, respectively, for the observed sources.

seen by chance in the line of sight toward the Galactic Center [see discussion in [te\[cite.van92van Langevelde et al. \(1992\)\]](#)].

The best fit for the radial velocities gives $V_{\text{lsr}} = -19.2(\pm 7.9) + 0.085(\pm 0.020)(\Delta l / \text{arcsec}) \text{ km s}^{-1}$ and the standard deviation from this line is 69.8 km s^{-1} for the 79 sources. Here, Δl is the Galactic longitude offset from Sgr A*, the dynamical center of the Galaxy (R.A. = $18^{\text{h}}45^{\text{m}}40^{\text{s}}.05$, Dec. = $-29^{\circ}00'27''.9$, J2000; 000 [cite]cite.rog94Rogers et al. (1994)). If we remove the two sources with $|V_{\text{lsr}}| > 200 \text{ km s}^{-1}$, the best fit gives $V_{\text{lsr}} = -12.1(\pm 6.4) + 0.078(\pm 0.016)(\Delta l / \text{arcsec}) \text{ km s}^{-1}$. The best-fit slope, 0.085 km s^{-1} per arcsec, which corresponds to 306 km s^{-1} per degree, is compatible with the value, $\sim 190 \text{ km s}^{-1}$ per degree, which was computed from the OH 1612 MHz data within 0.5 degree from the Galactic center (000 [cite]cite.sjo98Sjouwerman et al. (1998)). Considering the slow rotation of the inner Bulge out to 3° from the Galactic center, $\sim 20 \text{ km s}^{-1}$ per degree (000 [cite]cite.deg00aDeguchi et al. (2000a)a), we conclude that the nuclear disk is rotating more rapidly than the inner Bulge.

The zero intercept at $\Delta l = 0$ is negative, which is consistent with previous SiO maser observations (000 [cite]cite.izu95Izumiura et al. (1995); 000 [cite]cite.deg00aDeguchi et al. (2000a)a). This can be interpreted as the motion of the local standard of rest toward the dynamical center of the Galaxy (000 [cite]cite.izu95Izumiura et al. (1995)).

The overall structure of the SiO l - v diagram is quite similar to the OH l - v diagram in the same region (see figure 3 of 000 [cite]cite.sjo98Sjouwerman et al. (1998)). We can recognize a hole in the SiO distribution at ($\Delta l = 150''$, $V_{\text{lsr}} = 80 \text{ km s}^{-1}$) in figure 2. The same hole can be seen in figure 3 of [te\[cite\]cite.sjo98Sjouwerman et al. \(1998\)](#) ([cite]cite.sjo98Sjouwerman et al. (1998)), though another hole at ($\Delta l = -200''$, $V_{\text{lsr}} = 0 \text{ km s}^{-1}$) in figure 3 of [te\[cite\]cite.sjo98Sjouwerman et al. \(1998\)](#) ([cite]cite.sjo98Sjouwerman et al. (1998)) is not present in figure 2 of the present paper. It is known that a bar potential produces a characteristic pattern in the l - v diagram (000 [cite]cite.kui95Kuijken, Merrifield (1995)). Non-circular streaming motions of stars may be present in the nuclear disk region in our Galaxy, and the hole in the l - v diagram can be a signature of bars within the bar, such as have been found in other galaxies (000 [cite]cite.erw01Erwin et al. (2001)). An alternative interpretation is that the stars within $100''$ from the Galactic center have a large circular motion ($\sim 1.1 \text{ km s}^{-1}$ per arcsec; 000 [cite]cite.deg02Deguchi et al. (2002)). The magnitude of the circular motion is comparable with that of the circumnuclear ring revealed by the molecular line observations (e.g., 000 [cite]cite.wri01Wright et al. (2001)). It is possible that the rapidly rotating AGB stars near the Galactic center were born as a result of star formation in the circumnuclear ring (000 [cite]cite.lev95Levine et al. (1995)).

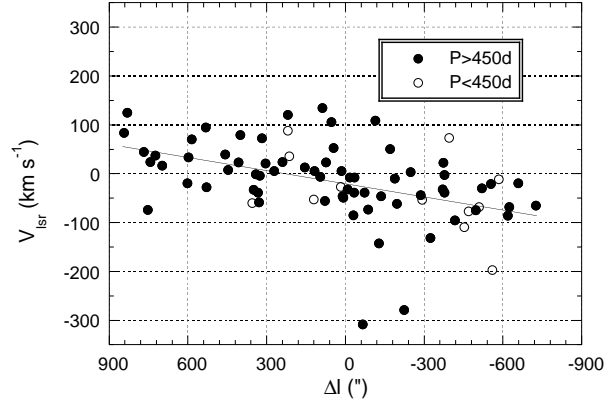


Fig. 2. Longitude–Velocity diagram for the detected sources. The filled and open circles indicate the stars with periods above and below 450 d, respectively. The best linear fit is shown by the solid line.

4. Conclusion

We surveyed 134 large-amplitude variables within $15'$ of the Galactic center, and obtained 79 detections in the SiO maser lines. The SiO detection rate of $\sim 60\%$ is comparable with the previous SiO survey of color-selected bulge IRAS sources. The SiO detection rate increases with the period of the light variation, and is well correlated with the OH detection rate. The longitude-velocity diagram of the SiO sources has been revealed to be quite similar to the OH l - v diagram. These facts suggest that these large-amplitude variables in the Galactic nuclear disk are mass-losing stars in the AGB phase, quite similar to the IRAS sources in the inner Galactic Bulge.

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